OMI, emissions inventories, and detection of missing sources

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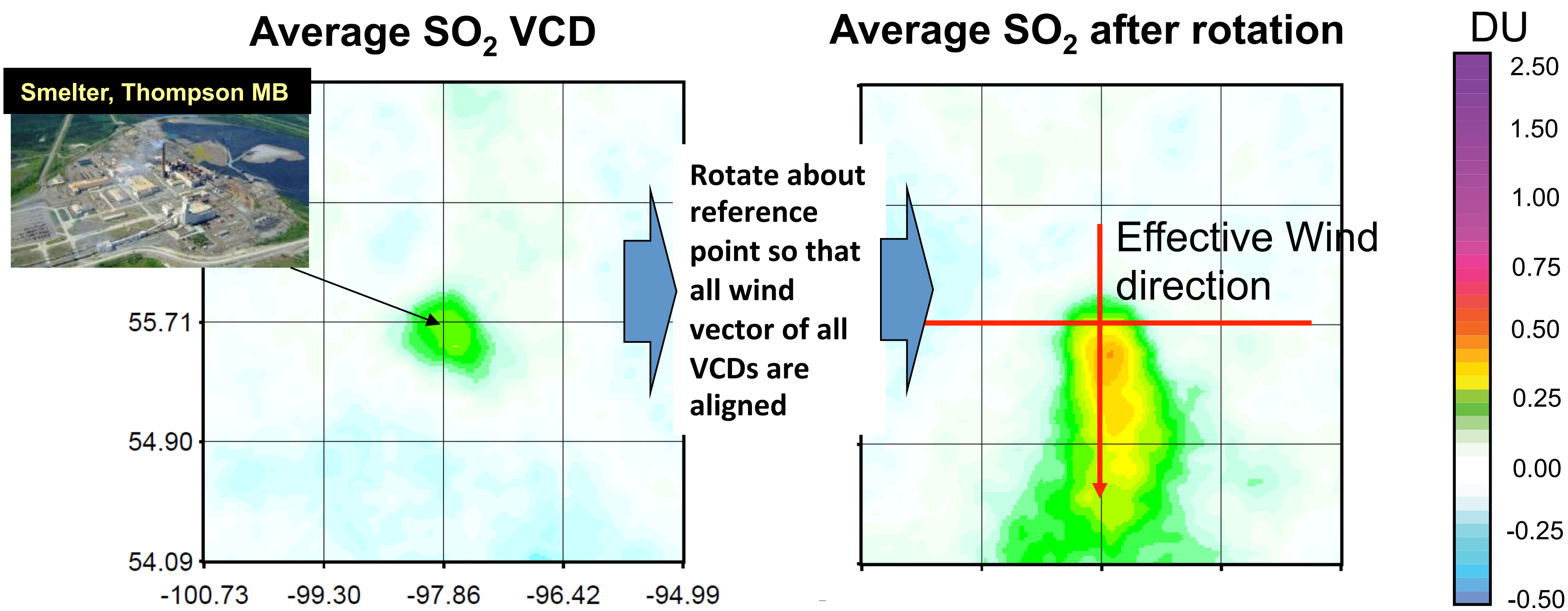
Introduction

- There are different methods for quantifying emissions from satellite data;   see review article by Streets et al., 2014; http://dx.doi.org/10.1016/j.atmosenv.2013.05.051
- Here we use OMI measurements of SO_2 to detect and quantify global SO_2 emissions
  - SO_2 data is from NASA PCA algorithm (Li et al., 2013), 2005-2015
  - Wind profile information from the ECMWF reanalysis interim product is mapping onto each OMI SO_2 Vertical Column Density (VCD) measurement
- OMI data is analyzed after it has been rotated about a reference point in order to co-align the wind direction of each measurement (see Pommier et al., GRL, 2012)
  - This conserves the relative downwind-upwind location, relative to the reference location

Rotation Example

- The mean SO_2 VCD distribution looks like a plume
- Peak values in the rotated frame typically increase
- An analysis of the downwind decay of pollutant can be used to derive emissions



Identification of sources

- Define high-resolution grid over area of interest
- Test every grid-point to see if it is a source:
  - Align wind vectors by rotating about this point
  - Determine downwind-upwind difference in SO_2 VCD
- Criteria for source detection:

$$VCD_{dw} - VCD_{uw} > 2(SEM_{dw} + SEM_{uw})$$

VCD = average vertical column density

SEM = standard error of the mean

dw / up = downwind / upwind

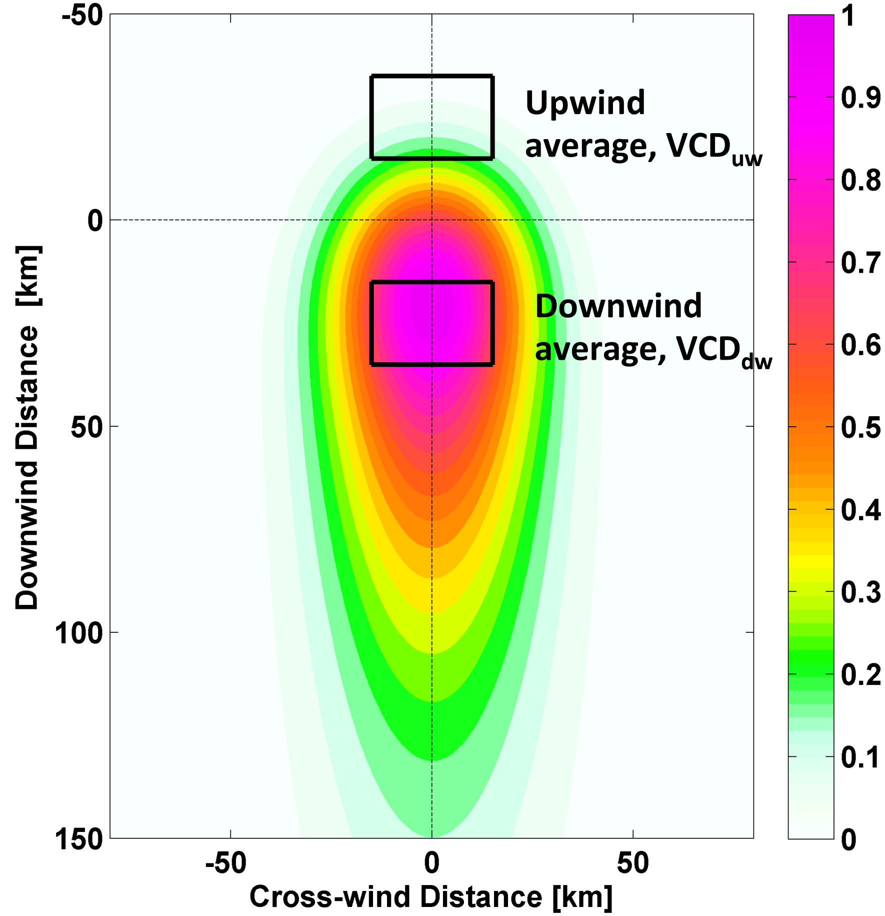
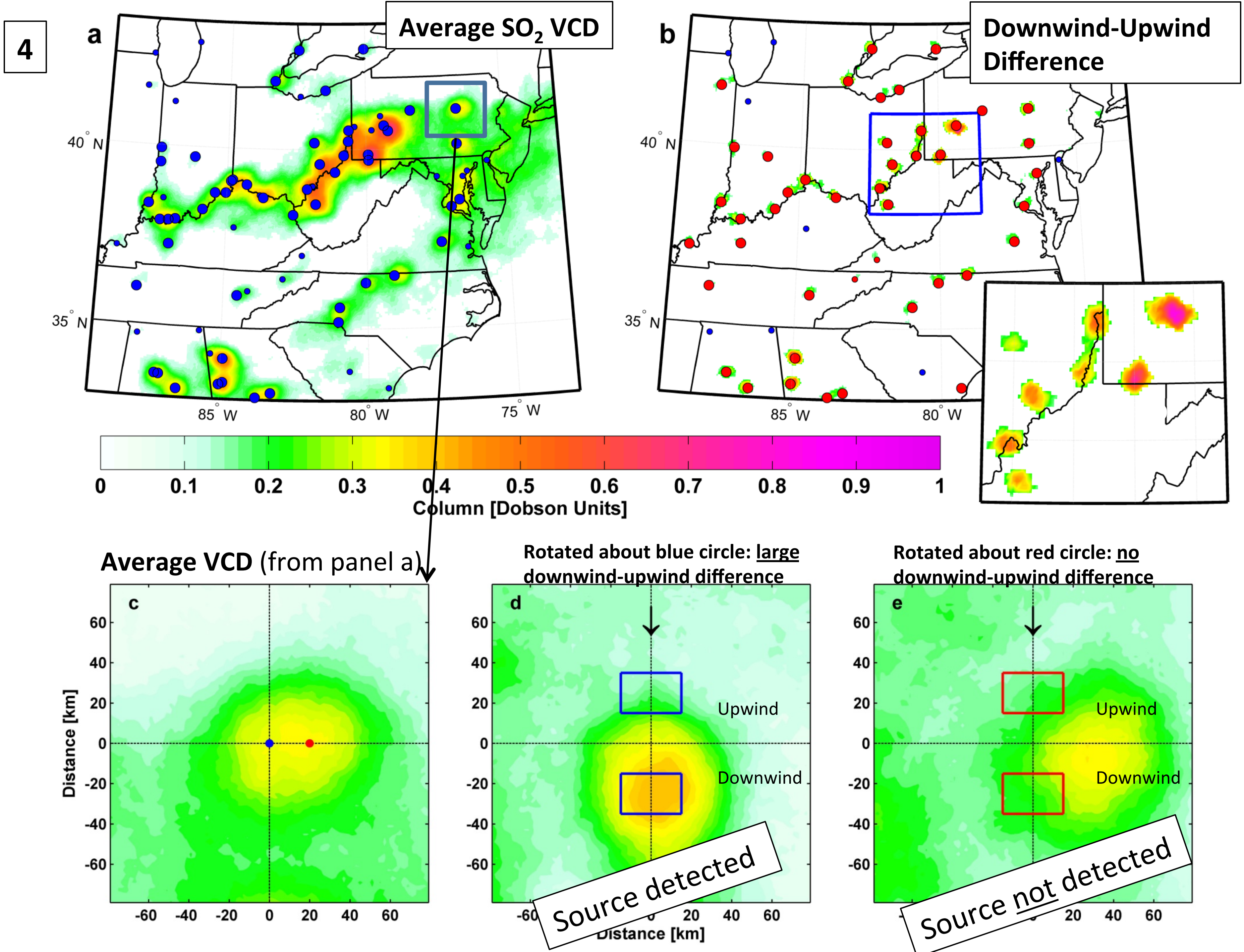


Figure above: Idealized average SO_2 VCD in rotated frame

Figure below: Application to the Eastern-US. Top: The downwind-upwind VCD difference map shows very localized peaks indicating the location of sources. Bottom: The downwind-upwind difference decreases rapidly just a few km from the source location.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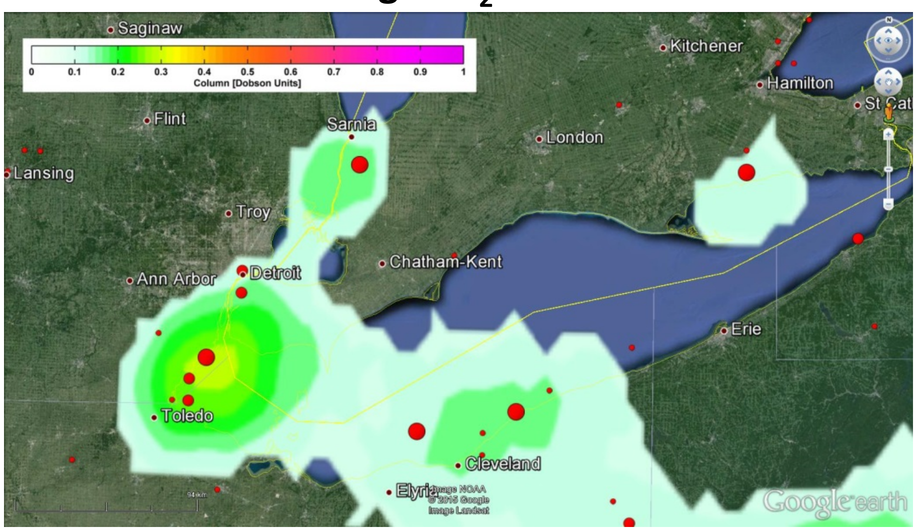
a
Average SO_2 VCD
b
Downwind-Upwind Difference
40° N
35° N
85° W
80° W
75° W
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Column [Dobson Units]
Average VCD (from panel a)
Rotated about blue circle: large downwind-upwind difference
Rotated about red circle: no downwind-upwind difference
c
d
e
Distance [km]
Upwind
Downwind
Source detected
Source not detected

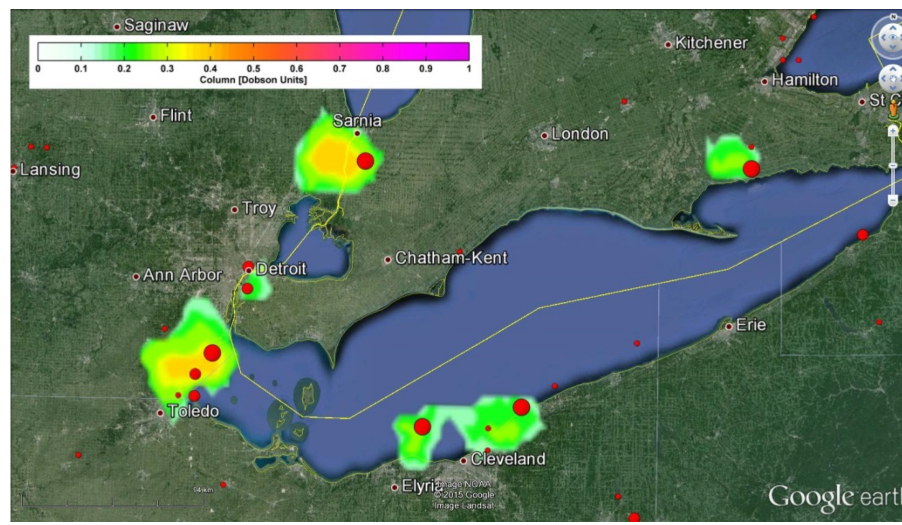
Comparison

- Downwind-upwind difference is almost always better than average VCD at locating sources and discriminating between sources and artefacts
- Downwind-upwind difference hotspots are localized about source, the detection limit about 30 kt/yr
- Sources within 20 km cannot be resolved

Average SO_2 VCD



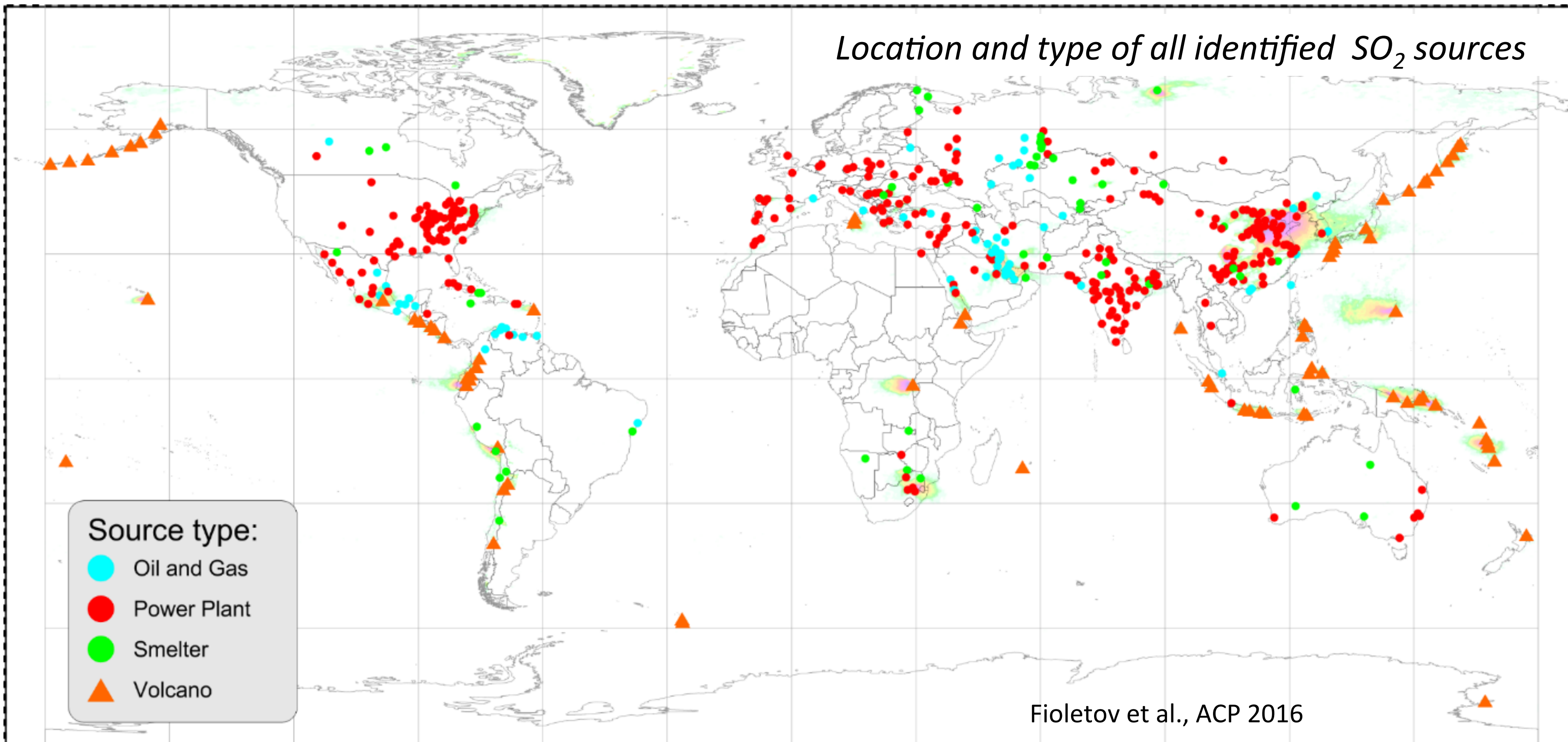
Downwind-Upwind difference in SO_2 VCD



Sources from the HTAP emissions inventory

OMI SO_2 Inventory (or catalogue)

- Global search resulted in ~500 verified emission sources
- Annual emissions were quantified (Fioletov et al., 2015) for 298 power plants, 53 smelters, 64 oil and gas sources, 78 volcanos
- Catalogue includes: source location, name, type, 2005-2015 annual emissions

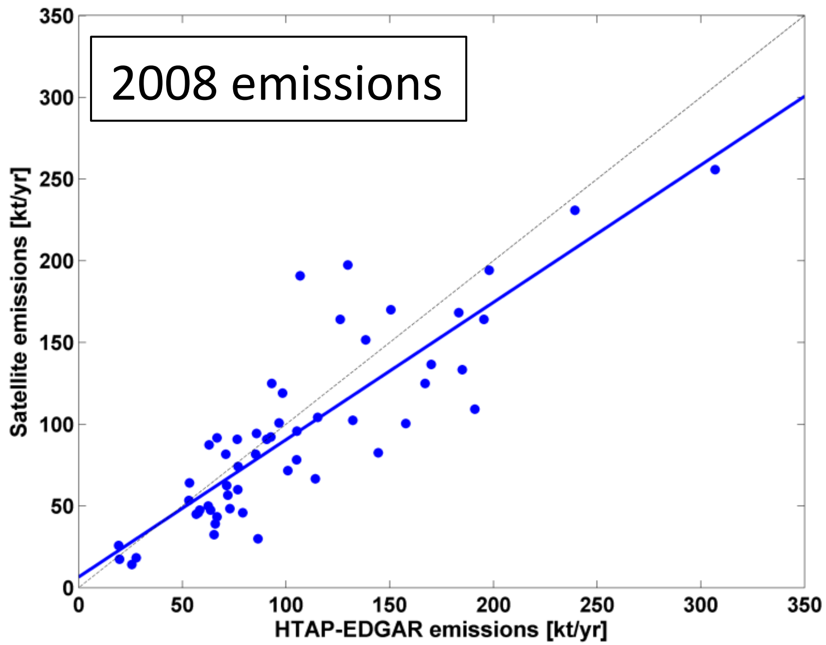


Algorithm Verification

Eastern-US power plants are used to evaluate the algorithm

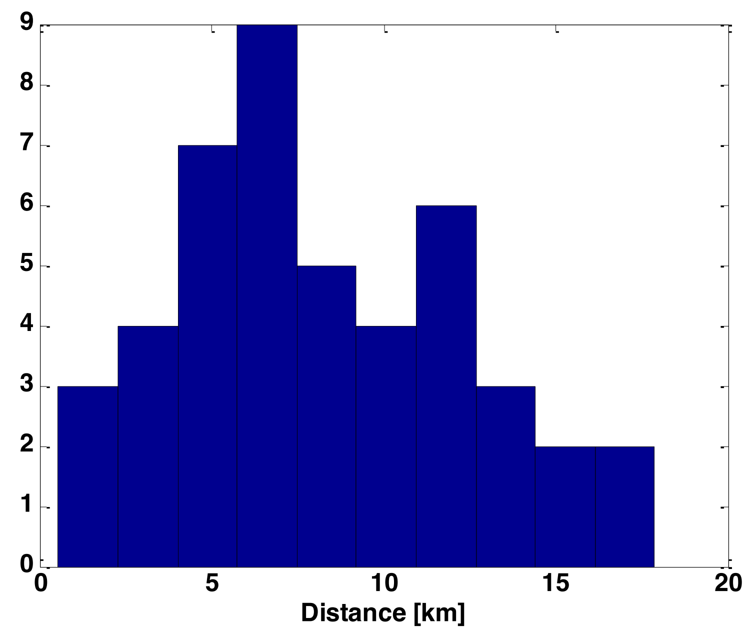
Magnitude of Emissions

- HTAP-EDGAR emissions integrated over a 50 km about the reference location
  - Even better agreement is seen using the facility level emissions

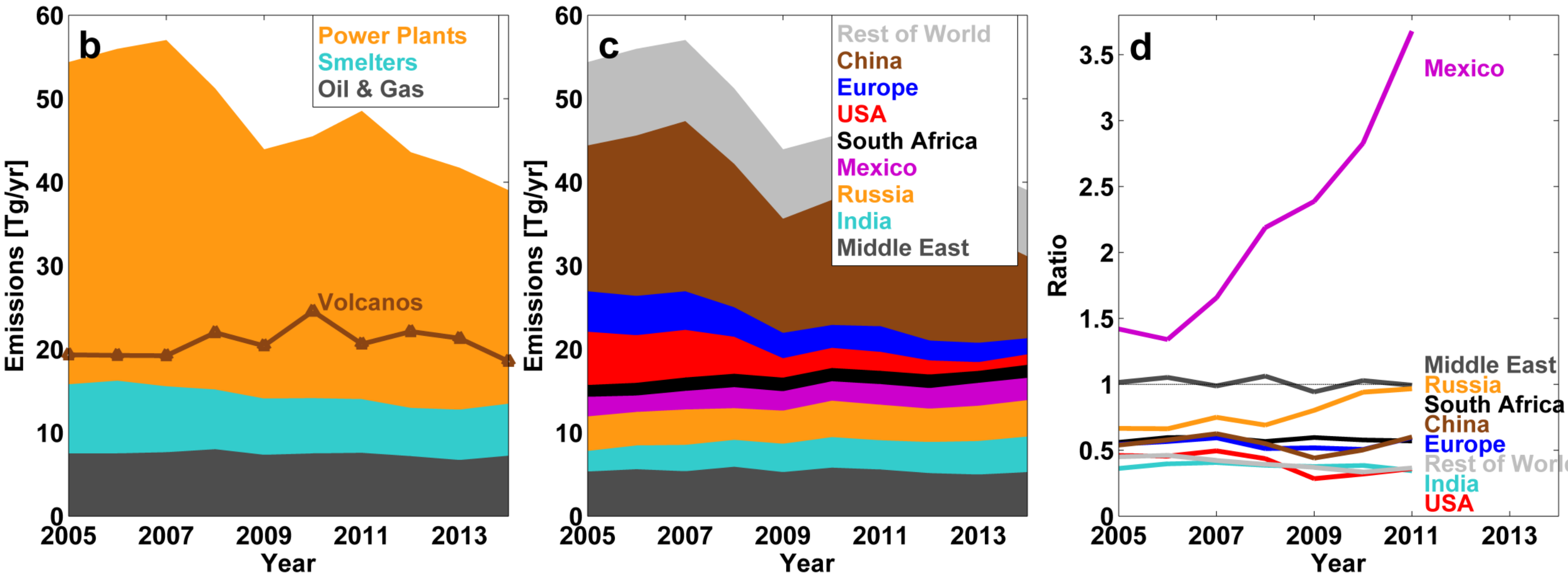


Location of Emissions

- Distance between the location of peak in source map (from 2D peak-finder) and the actual facility
  - Locate to within 8 ± 4 km



Global sources



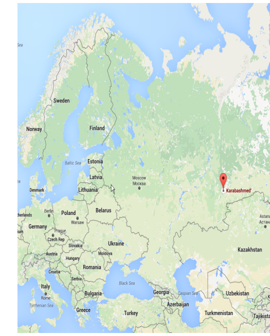
Total annual emission by source type. The total anthropogenic source is roughly 50 Tg/yr, roughly half that in the bottom-up inventories. This is mainly due to the OMI detection limit of 30 kt/yr.

Total annual anthropogenic emissions for selected regions.

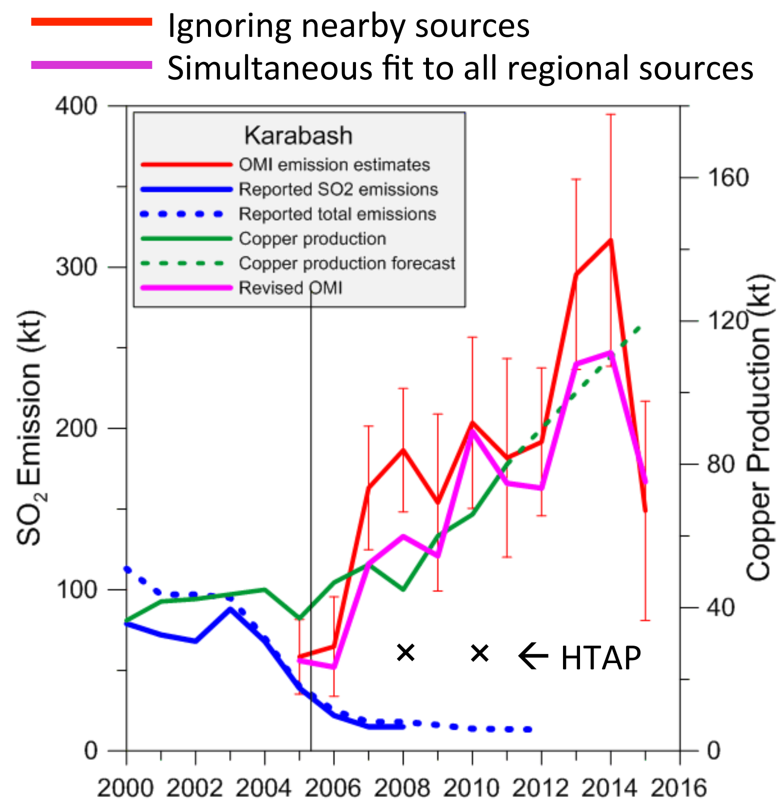
Ratio of OMI regional emissions to that from a bottom-up inventory. A ratio of about 0.5 is expected given the OMI detection limit. A ratio of 1 or more indicates a significant discrepancy between the two. Mexico is particular glaring due to unaccounted emission from the Cantarell oil fields.

Example: Karabash Smelter in Russia

Karabash smelter (founded in 1837) is one of the oldest and largest copper smelters in Russia. An SO_2 signature is clear in OMI



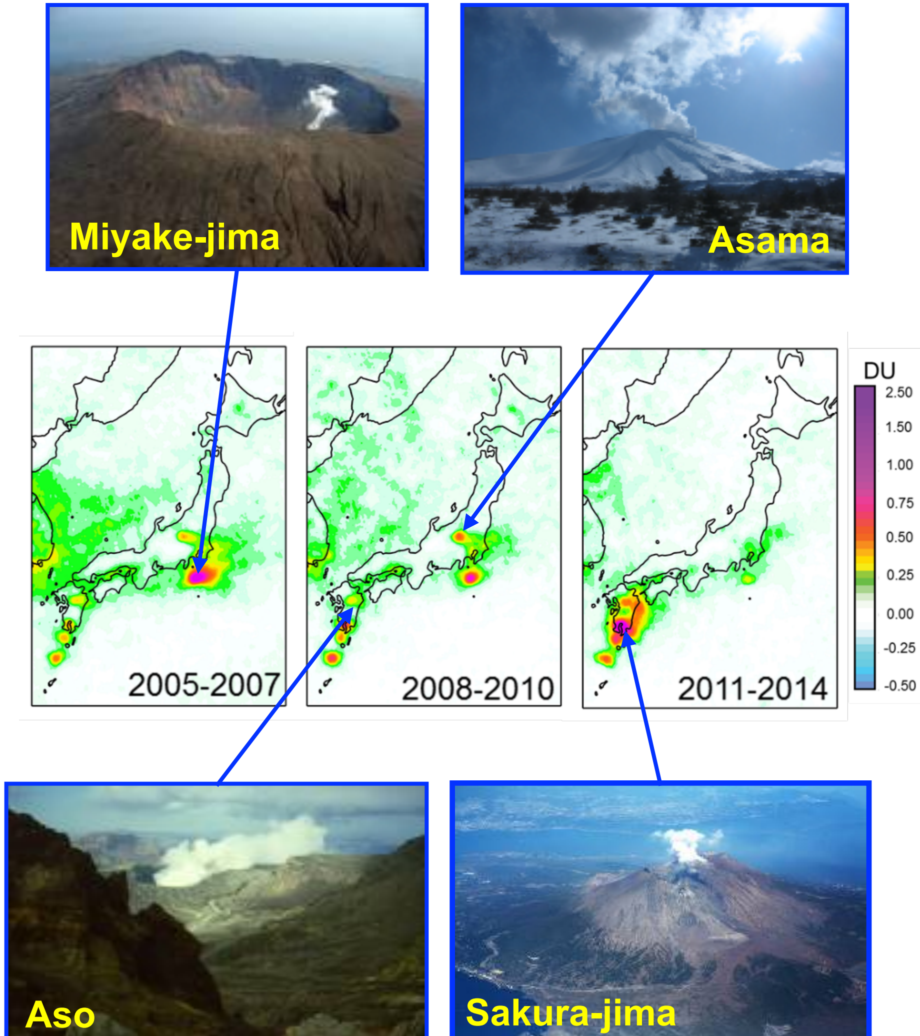
- In 2005, the plant owner reported installation of scrubbers, but complains about high pollutions continued
- large discrepancies between reported and estimated emissions
- The scrubbers are evidently not effective

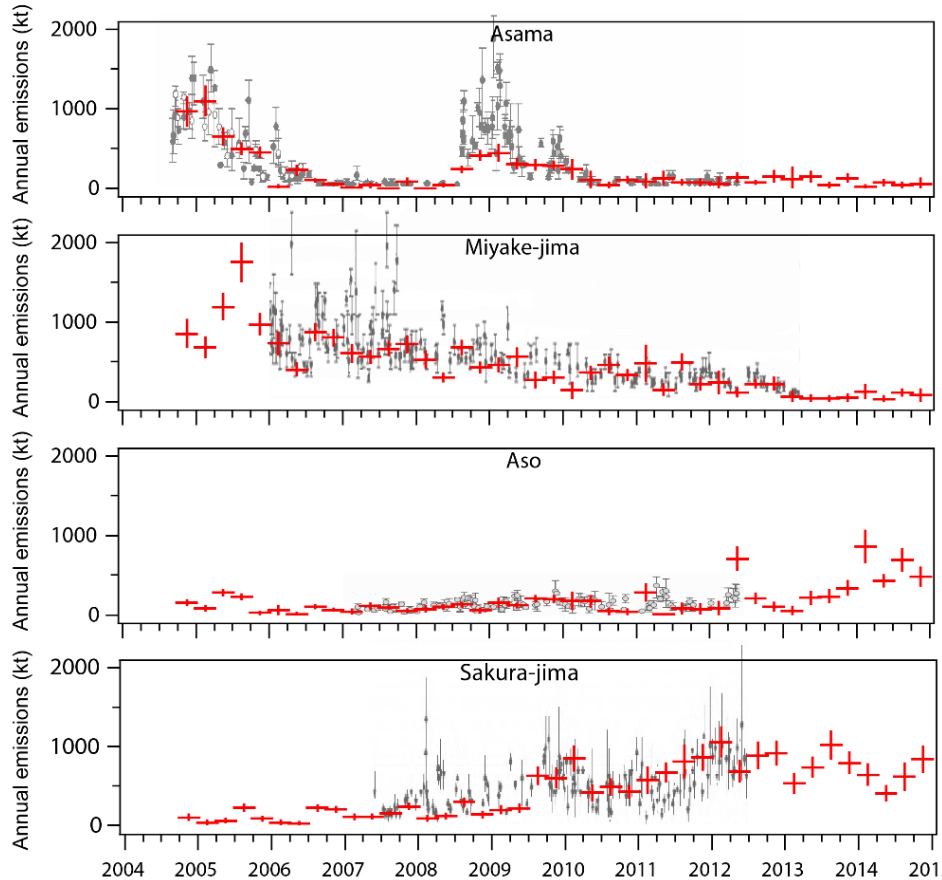


Right: Comparison of OMI SO2 emissions with those reported by the plant operators

Example: Degassing from Volcanos

Below: Mean SO_2 VCD near Japanese volcanos

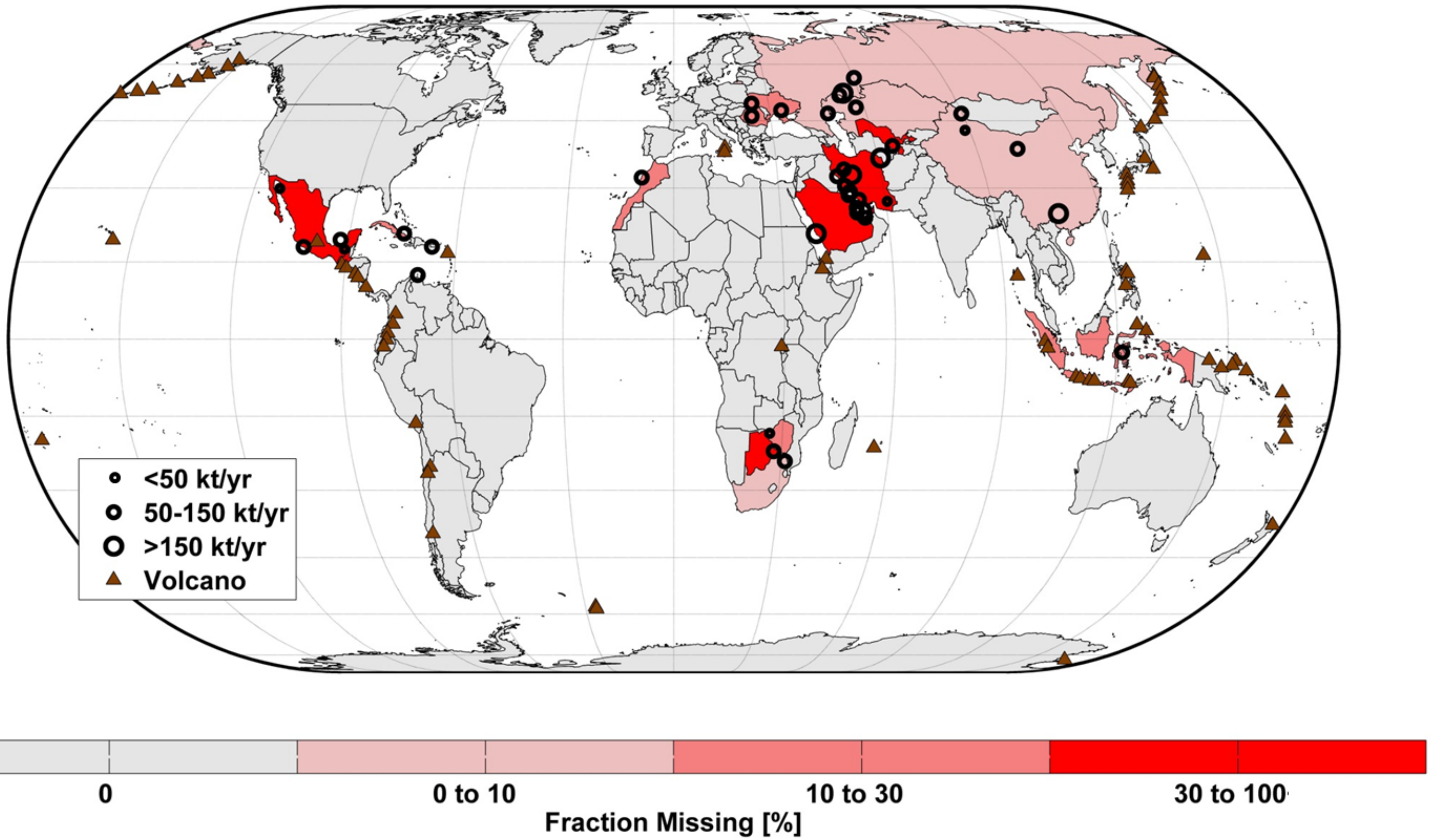




Above: Time series of OMI emission rates calculated for every 3 months for four volcanoes (red). Grey dots are daily emission estimates provided by Japan Meteorological Agency.

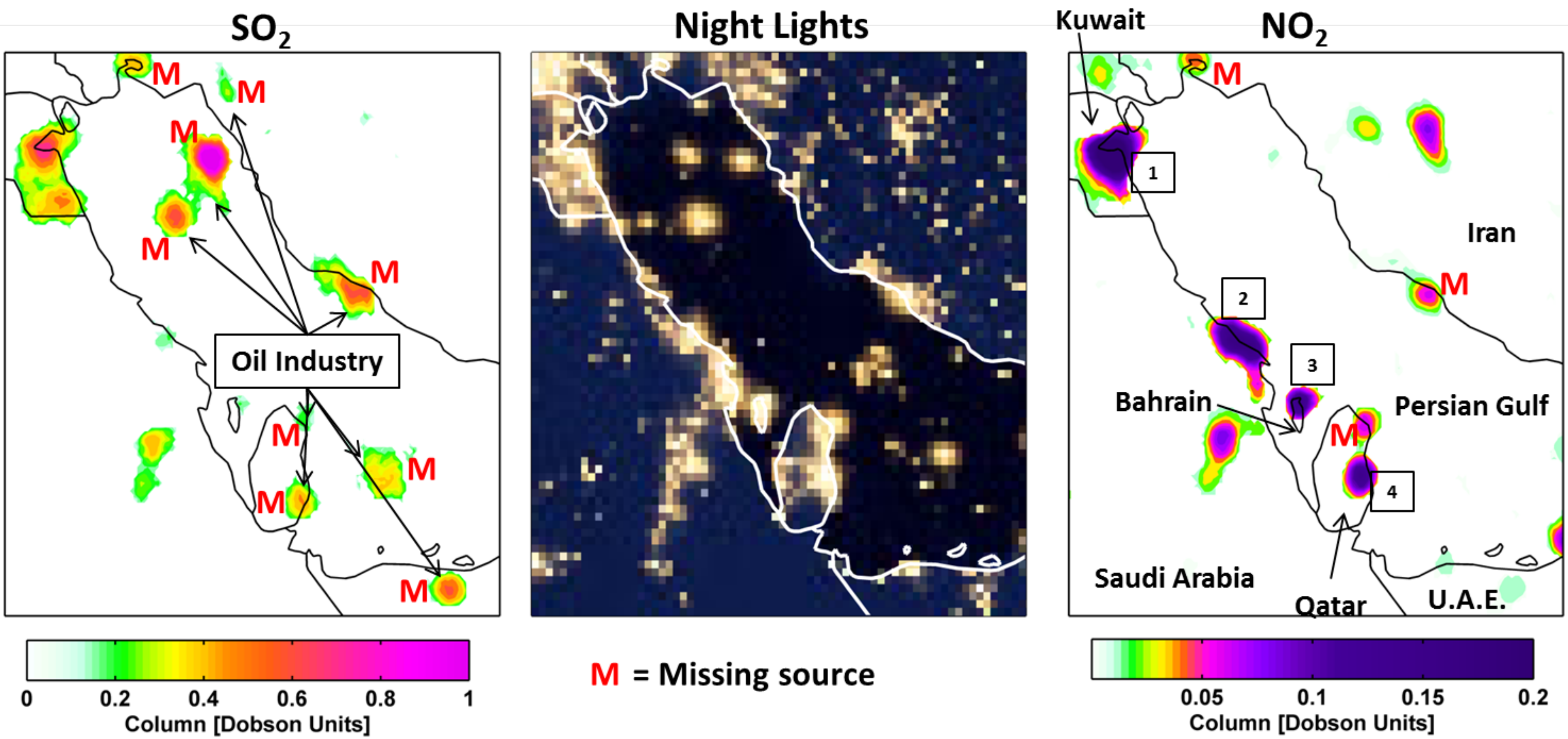
Missing Sources

- Catalogue includes 39 verified sources missing from HTAP, EDGAR, and MACCity emissions inventories



The location of the missing sources and the volcanos. Each country is coded according to the fraction of its total source that is missing from the HTAP inventory. These missing sources represent about 6% of the anthropogenic total. Considering only half can be detected, it is estimated that 12% is unaccounted for in bottom-up inventories

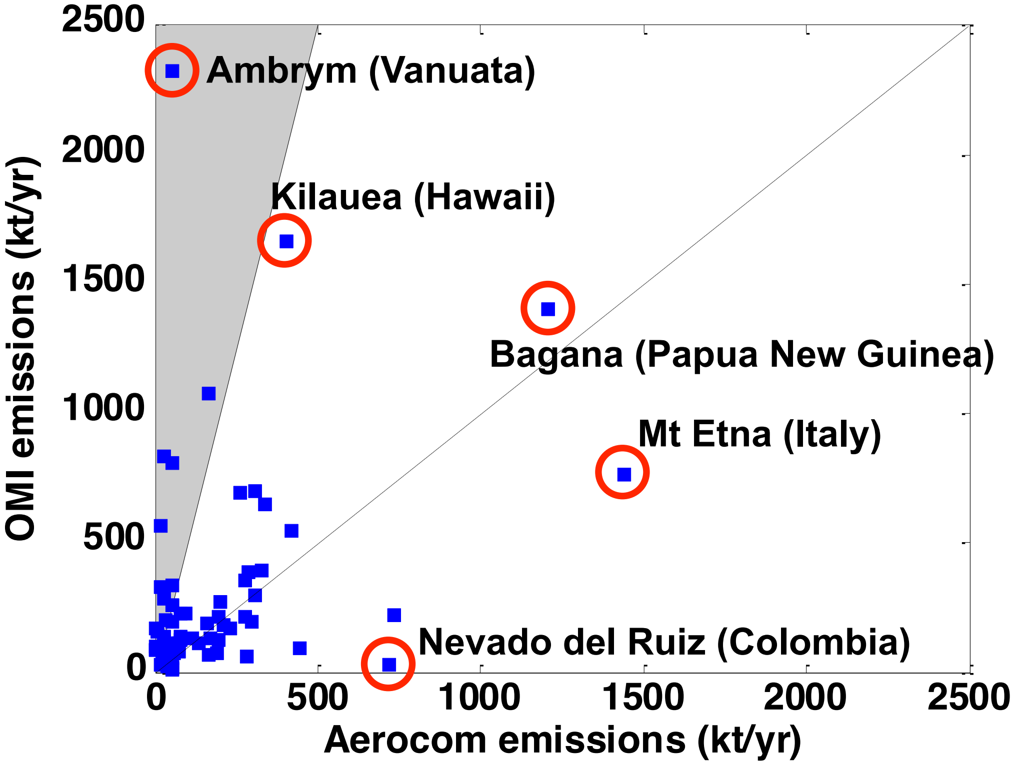
Persian Gulf



Left: OMI SO_2 downwind-upwind difference (2007-2009). There are at least 9 large SO_2 sources identified by OMI that are unaccounted for in the HTAP, EDGAR, and MACCity inventories. Middle: VIIRS night-light imagery indicating many of the SO_2 sources are also sources of flaring. Right: OMI NO_2 downwind-upwind difference. Some of the missing SO_2 sources are also missing from the NO_x inventories.

Volcanos

- "Aerocom" volcanic emissions inventory is recommended for use with HTAP and used by several models (e.g, GEOS-Chem and WRF-Chem)
- Passive degassing emissions from Aerocom and OMI do not compare well; Aerocom uses "fill values" for many volcanos



Comparison of OMI and Aerocom volcanic emissions, averaged over 2005-2010. The correlation coefficient is 0.36. Few of the Aerocom emissions are based on measurements.

Application to OMI NO_2

Downwind-Upwind difference of OMI NO2 can be used to identify NO_x sources

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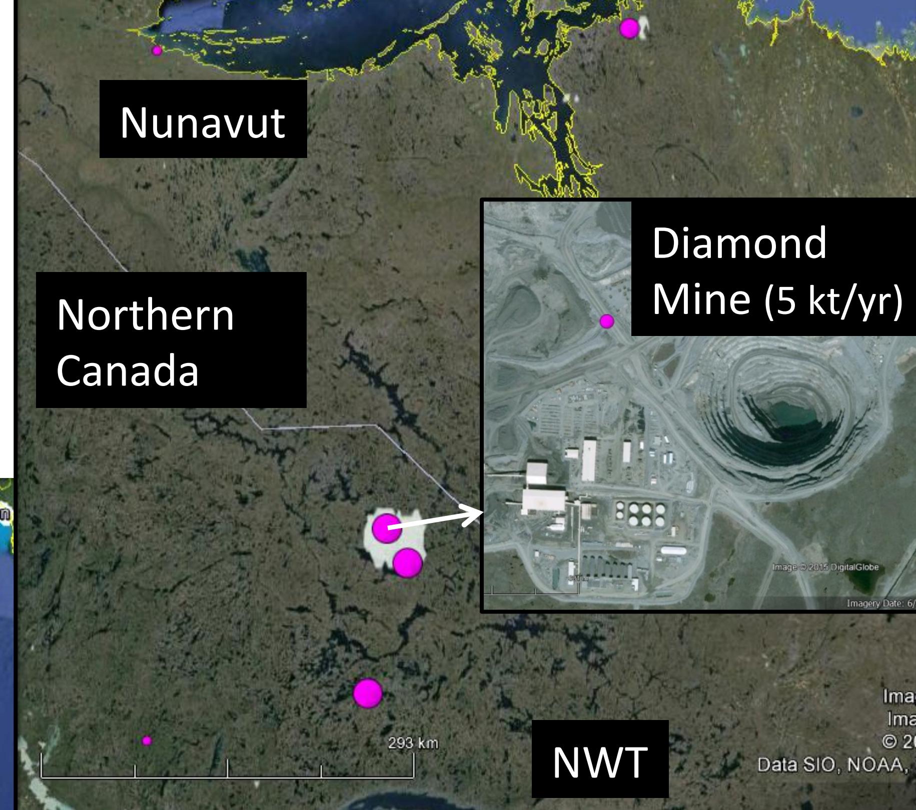

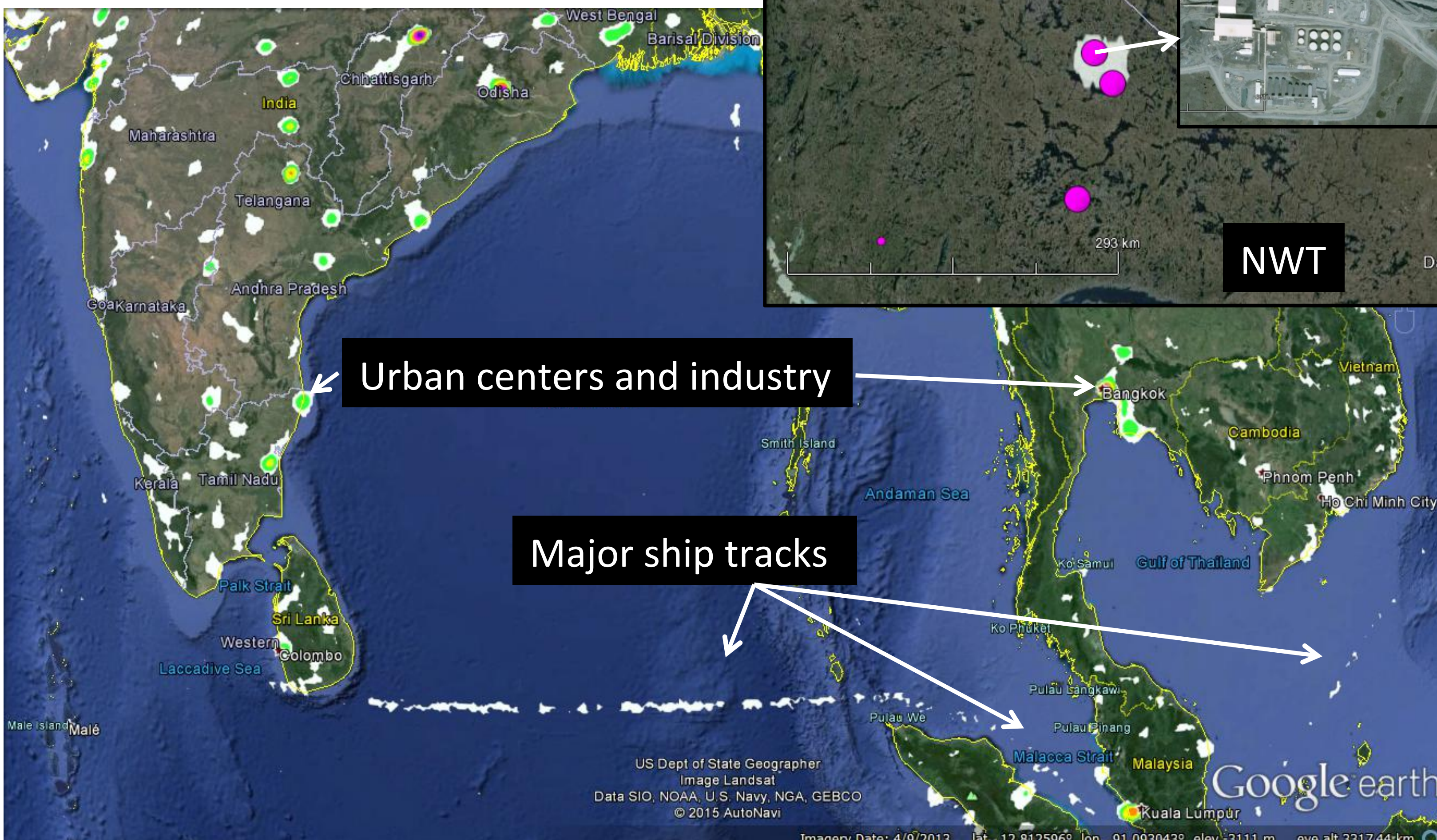

Summary

- OMI is able to both detect and quantify emissions of SO_2 independent of conventional emissions knowledge sources
  - A global SO_2 inventory was created that is complimentary to bottom-up inventories
- OMI NO_x inventory is also possible (if more complex)
  - PM (from AOD) also works, perhaps NH_3 as well; CH_4?, CO_2?

References

This work is based on the following papers:

McLinden et al., *Nature-Geoscience*, doi: 10.1038/ngeo2724, 2016

Fioletov et al., *ACP*, doi:10.5194/acp-2016-417 2016

Fioletov et al., *GRL*, doi:10.1002/2015GL063148, 2015

Pommier et al., *GRL*, doi:10.1002/grl.50704.2013, 2013